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MAINTENANCE IMPROVEMENT: AN ANALYSIS APPROACH INCLUDING INFERENTIAL TECHNIQUES

VOLUME I

OVERVIEW

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This final report, contained in four volumes, presents the results of research into assessing the economic (cost and down-time) impact of Potentially Avoidable Maintenance actions for selected Naval aircraft subsystems. Maintenance actions requiring no repair and those resulting in induced defects and failure-to-correct were identified. Specific high-driver two-digit Work Unit Codes were analyzed for the F-14A Fire Control, S-3A Bombing Navigation, S-3A Landing Gear, and A-7E Bombing Navigation.

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20. The content of the respective volumes of this report are as follows:

Volume I - Overview

Volume II - Technical Report - includes the research methodology, results, and recommendations. The Interim Feasibility Report is an appendix to Volume II.

Volume III - Detailed Technical Data - includes the computer-generated input information tables and output data tables which form the foundation for the results contained in Volume II.

Volume IV - Software Manual - includes the logic used to develop software for generating the tables in Volume III, user instructions, and a complete listing of programs that were executed to arrive at the tables.

For the respective aircraft studied, only data from squadrons within CNAL were utilized. These results were used to project the cost and down-time impact of Potentially Avoidable Maintenance for the whole fleet of the subsystems studied.

The study made a coarse evaluation of Built-In Test effectiveness for one subsystem. Fault isolation capability regarding Shop Replaceable Assemblies was also assessed.

The study concluded that Potentially Avoidable Maintenance contributes significantly to maintenance costs and aircraft down-time, and recommends actions to identify and control the causes.

VOLUME I - OVERVIEW

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FOREWORD

This Final Report was prepared for the Department of Defense, OASD (MRA&L) by Information Spectrum, Inc., Warminster, PA, under Contract No. MDA903-78-C-0176 (Contract Period 27 December 1977 through 15 March 1979.)

This report describes work covered during Phase II (17 April 1978 to 15 March 1979) and consists of four volumes:

Volume I - Overview

Volume II - Technical Report

including the Phase I Feasibility Study (27 December 1977 to 7 April 1978) as an Appendix

Volume III - Detailed Supporting Data

Volume IV - Software Manual

The principal contributor to this volume was Mr. Philip S. Grenetz, Senior Systems Analyst; under the direction of Mr. Milton Clyman, Executive Vice President.

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OVERVIEW

A. INTRODUCTION

Today, the Military Services incur increasingly significant costs for Operation and Support (O&S) of airborne weapon systems. Maintenance contributes a large share of this O&S expense. The gap between inherent reliability and that which is exhibited in the field is believed to be a productive area for maintenance cost and down-time reduction.

Defects can be induced on equipments during maintenance, transportation, and handling. These are denoted here as Potentially Avoidable Maintenance (PAM) because their rate and cost of occurrence could be reduced by appropriate improvements in Built-In Test (BIT), maintainability design, support concepts, and support resources, e.g., test equipment, technical data, personnel skills, etc.

Failure of maintenance technicians to correct malfunctions on the first attempt (that is, the first such reported maintenance action) results in additional attempts to correct. The Services' Maintenance Data Reporting (MDR) systems account for each attempt as a separate failure, although only one failure has occurred. Thus, this Failure-To-Correct phenomenon adversely affects field reliability. Induced Defect actions represent potentially avoidable failures which also degrade the calculated value of field reliability.

False BIT indications and the failure of maintenance technicians to verify and diagnose discrepancies at first attempt result in

removals of equipment which are denoted by the Services' MDR systems as No-Repairs-Required actions. Some of these PAM actions are compounded by the fact that they can lead to other PAM actions, in particular cannibalizations and access actions, i.e., remove-and-reinstall actions for access purposes. No-Repairs-Required actions, while not included in the calculation of reliability, can have a pronounced impact on maintenance action frequencies.

Two categories of Potentially Avoidable Maintenance are explicitly identified within the Services' MDR systems by the use of appropriate Action Taken Codes and How Malfunctioned Codes: (1) No-Repairs-Required and (2) Induced Defect. Because of human aversion for self-blame, very few Induced Defect actions are reported as such. Existing MDR procedures and processing software do not identify occurrences of Failure-To-Correct, nor do they categorize No-Repairs-Required actions as to the reasons behind them, e.g., unverified complaints, false BIT indications, multiple removals/replacements for quick repair.

A hypothesis that led to this study is that many of the PAM actions which are not reported as such could be identified and categorized by inference via tracking a piece of equipment through the maintenance cycle using data provided by the existing MDR system. The process is tedious and involves millions of data point comparisons, so that computerization was the only feasible way to implement the analytical logic.

The term "potentially avoidable" is applied to the above categories of maintenance actions to emphasize the following ideas. It is not expected that PAM can be entirely eliminated. Indeed, were it possible to do so, the investment costs incurred to achieve that objective would probably be prohibitive. Before the optimal investment programs for maintenance improvement can be developed, further investigation (beyond that conducted here) will be necessary to identify the underlying causes of PAM and the degree to which each cause would respond to investment in each type of improvement.

B. PURPOSE

One objective of the study was to develop a technique for identifying, through existing data bases, occurrences of various types of PAM actions and for assessing their impact in terms of cost and Not Operationally Ready (NOR) time. The Potentially Avoidable Maintenance studied includes these categories: No-Repairs-Required actions, Failure-To-Correct defects, and Induced Defects.

Implementation of the technique on a sample of subsystems (two-digit Work Unit Codes (WUCs)) of sample aircraft Type/Model/Series (T/M/S) found to be large contributors to maintenance cost was the next objective. Specific Weapon Replaceable Assemblies (five-digit WUCs) to which PAM cost and NOR time are attributable were to be identified.

Finally, the relationship of Built-In Test (BIT), and failure diagnosis in general, to the problem of Potentially Avoidable Maintenance were to be analyzed with data from existing sources.

This study was one step in an effort whose ultimate purpose is to develop a procedure by which economically sound decisions can be made in the planning stages of new weapon systems by all of the Services to reduce the expected occurrence of Potentially Avoidable Maintenance by wisely investing in maintainability design, training, and logistic resources. In addition, it should be possible to use the technique to pinpoint five-digit WUCs, on existing operational aircraft, the maintenance improvement of which would be cost-effective.

C. PROBLEM

The application of ordinary data analytical techniques to this study would be of limited benefit. Only two categories of Potentially Avoidable Maintenance are explicitly reported under present Maintenance Data Reporting (MDR) systems. One of these, No-No-Repairs-Required actions, is not categorized according to the reasons behind them. The other category, Induced Defect actions, is seldom reported as such. Human nature contributes to this problem by the reluctance to admit error.

The structure of the MDR system prevents the direct reporting of other types of Potentially Avoidable Maintenance as well. The following discussion is based on the Navy's aviation system as an example. The maintenance cycle involves the flow of a piece of equipment from the aircraft or Organizational (O)-Level maintenance and, as appropriate, to Intermediate (I)-Level maintenance. If the equipment is transferred to the I Level, it is

either repaired, returned as a No-Repairs-Required action, discarded as Beyond Economical Repair, or transferred to the depot as Beyond Capability of Maintenance (BCM) at the I Level. The depot would either repair the equipment, discard it, or return it as a no-defect action. With the exception of Depot Customer Service, the depot will return it to the supply system, which will return it to any Intermediate Maintenance Activity (IMA), not necessarily the one which transferred it to the depot. If the I Level returns an equipment to base supply, it may be installed at a later date on any aircraft served by that IMA.

The reporting system is not designed to track the progress of an equipment through all of the paths in this network. There is no way within the existing Maintenance Data Reporting system to identify no-defect actions at the depot. This category was, therefore, excluded from the present study.

The Maintenance Material and Management (3M) MDR system compounds the tracking problem in the following way. Only one part serial number is carried through the system from the Maintenance Action Form (MAF). On the MAF for a remove-and-replace action, entries are provided for the serial numbers of both the removed and replacement items, but only the serial number of the removed item is carried through the 3M system. Thus, the date of installation of equipments is not directly discernible. This date marks the beginning of a time interval which could be scanned for subsequent related maintenance actions.

Another drawback of the reporting system, from the standpoint

of its application to this study, is its characteristic of recording successive passes through the maintenance cycle, whether or not related, as separate maintenance actions. For instance, the failure to correct a defect on the first attempt may be expected to result in at least one additional action, representing further attempts to repair. Such subsequent actions would have different identifying Job Control Numbers (JCNs). Another example would be the inadvertent damage occurring to a piece of equipment during a maintenance action, undiscovered until a later date. This also will result in an additional repair action with a different identifying JCN.

The final drawback of the reporting system, as applied to this study, is its failure to identify, with one JCN, actions occurring on different, but related, equipments. For instance, if several related Weapon Replaceable Assemblies (WRAs) are removed over a period of time in an attempt to troubleshoot a discrepancy, separate JCNs are assigned, one for each WRA. If during the removal or installation of one assembly, damage is inadvertently induced in other assemblies, the corrective actions on the damaged equipments are all assigned individual JCNs.

A hypothesis that led to this study is that some of these difficulties could be overcome by developing algorithms for tracking, via appropriate identifying keys, sequences of related maintenance actions on the same equipment and on equipments related by physical proximity—denoted physically related WUCs—and diagnostic ambiguity—denoted functionally related WUCs.

D. SCOPE

This study was conducted in two phases—a feasibility study and a demonstration phase. The feasibility study verified the occurrence of Potentially Avoidable Maintenance, categorized the types of such maintenance actions feasible to study, and quantified one major category—Intermediate-Level No-Repairs-Required actions. The categories of PAM actions considered by this study and their definitions are provided in Tables 0-1 and 0-2. The associated cost elements are displayed in Table 0-3. Figure 0-1 depicts the categorization of PAM and provides the F-14A Fire Control PAM action quantity breakdown as an example. In addition, the total maintenance action quantity for that subsystem is provided for comparison.

Depot-level costs are incurred for depot transfers resulting from corrective actions necessitated by defects induced at the O&I Levels. Therefore, as can be seen, depot-level costs were assessed for some Potentially Avoidable Maintenance actions, even though PAM actions initiated or discovered at the depot were not studied.

All Beyond Capability of Maintenance (BCM) actions, occurring at the I Level, were treated as corrective actions. The possibility that some I-Level discard actions are unwarranted, i.e., the discarded assembly not truly Beyond Economical Repair, was considered during the feasibility study and eliminated for this analysis because no feasible method could be identified to infer occurrences of Unwarranted Discard from existing (or even modified or new)

TABLE O-1. CATEGORIES OF POTENTIALLY AVOIDABLE MAINTENANCE ACTIONS

- No-Repairs-Required

  All suspected failures which are unverified as reported on the Maintenance Data Reporting form.

  - Categorized

    Those actions which are categorized via inference as to the reasons behind them.

    - Failure-To-Acknowledge

      Rejection, as invalid complaints, of legitimate discrepancies reported by operations personnel.

    - Failure-To-Diagnose

      No-Repairs-Required actions resulting from inefficient O-Level troubleshooting procedures, i.e., "shotgun" and trial-and-error. These involve multiple removals of functionally related assemblies, simultaneous or over a period of time, and transfers to a higher maintenance level, in order to repair the aircraft.

  - Uncategorized

    No-Repairs-Required actions resulting from all other causes.

- Failure-To-Correct

  Repeated (one or more) unsuccessful attempts (that is, reported maintenance actions) to correct a defect.

- Reported Induced Defect

  Corrective actions reported on the Maintenance Data Reporting form as being induced by maintenance, transportation, or handling.

- Inferred Induced Defect

  Corrective actions resulting from induced defects not reported as such.

  - Internally Induced Defect

    Defects induced on an assembly during the maintenance (scheduled or unscheduled) of the same assembly.

  - Externally Induced Defect

    Defects induced on an assembly during the maintenance (scheduled or unscheduled) of a physically related assembly.

NOTE: Each of the above categories of Inferred Induced Defect is sub-divided according to the type of action which led to the defect: corrective or non-corrective.

TABLE O-2. ACTIONS POTENTIALLY RELATED TO I-LEVEL NO-REPAIRS-REQUIRED ACTIONS

- Potentially Avoidable Cannibalization

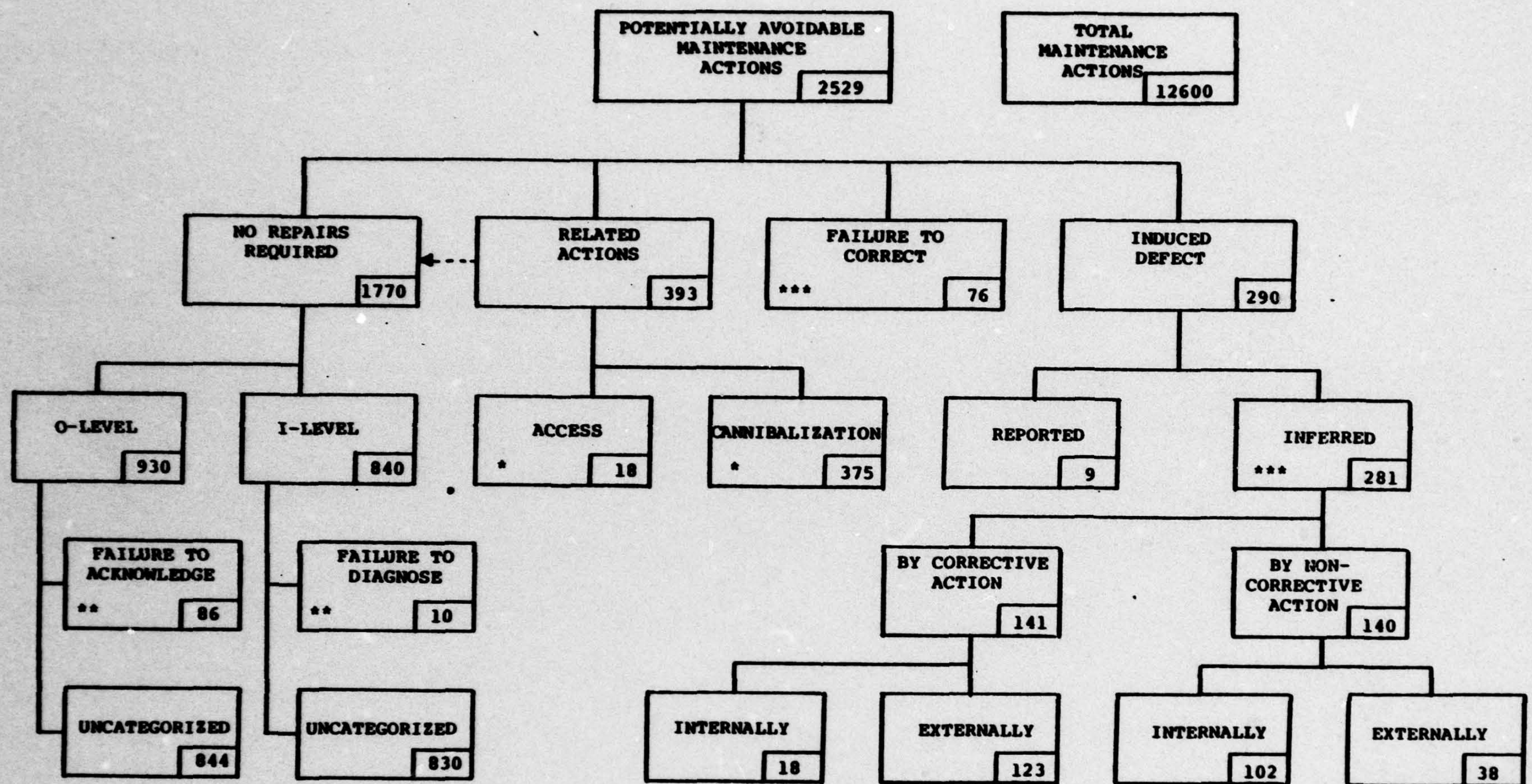
  Cannibalizations performed to replace equipments falsely removed.

- Potentially Avoidable Access

  Remove-and-reinstall actions performed to facilitate access to equipments whose removal ultimately results in a No-Repairs-Required action at the I Level.

TABLE O-3. COST ELEMENT STRUCTURE

OPERATING AND SUPPORT COST
BELOW-DEPOT MAINTENANCE
O&I-LEVEL LABOR
O&I-LEVEL MATERIAL
REPLENISHMENT SPARES
DEPOT MAINTENANCE
LABOR
MATERIAL
SECOND DESTINATION TRANSPORTATION
NOT OPERATIONALLY READY (NOR) TIME
DUE TO UNSCHEDULED MAINTENANCE (NORMU)
AWAITING MAINTENANCE (AWM)
PURE (NORMU(P))
DUE TO SUPPLY (NORS)



LEGEND:

Maintenance Action Category

Maintenance Action Quantity for F-14A Fire Control, CNAL Squadrons, FY 1977

* Reported actions, only those considered PAM by inferred relationship
** Reported PAM actions, cause inferred
*** Inferred PAM actions

Figure O-1. HIERARCHICAL BREAKDOWN OF POTENTIALLY AVOIDABLE MAINTENANCE

data sources. Similarly, the possibility that some assemblies which are transferred to depot maintenance are determined there to be non-defective was considered and deferred to future analysis.

During the feasibility study, existing data sources of the Services were examined to determine which source would be utilized for the demonstration phase of this study. The Navy's Analytical Maintenance Program Analysis Support (AMPAS) system was selected because of the accessibility of its detailed individual maintenance action data files—magnetic tape and hard-copy reports. In particular, each maintenance action is described by a single record containing such data items as Job Control Number (JCN), O&I action dates, O&I Action Taken Codes (ATCs), O&I How Malfunctioned Codes (HMCs), O&I Maintenance Man-Hours (MMHs), and down-time parameters in hours. In addition, maintenance cost data are readily obtained at the four-digit WUC level from the Navy's Visibility And Management of Operating and Support Cost (VAMOSC) Maintenance Subsystem (MS).

The modern fighter and anti-submarine warfare aircraft—F-14A and S-3A—were selected for study because they most closely reflect and anticipate future weapon systems and their maintenance problems. The A-7E, a more mature, less complex system, employing less advanced technology, was chosen as a point of comparison.

So that a single piece of equipment could be tracked by serial number through the maintenance cycle, all of the squadrons at one common site were studied for each selected aircraft T/M/S.

For convenience, the squadrons of the Commander of Naval Air Force, U.S. Atlantic Fleet (CNAL) were chosen. These squadrons are commonly sited, when based on land, for each aircraft T/M/S.

The subject WUCs selected for the demonstration phase were the two-digit WUC contributing the greatest quantity of I-Level No-Repairs-Required actions for each selected aircraft. In addition, for balance, the non-avionic two-digit WUC contributing the greatest proportion of I-Level No-Repairs-Required actions was selected for analysis. The resulting array of subject WUCs is:

T/M/S	WUC	SUBSYSTEM	CNAL OPERATING AIRCRAFT
F-14A	74	FIRE CONTROL	65
S-3A	73	BOMBING NAVIGATION	63
S-3A	13	LANDING GEAR	
A-7E	73	BOMBING NAVIGATION	157

The A-7E Bombing Navigation was only partially analyzed because of resource limitations.

Fiscal Year (FY) 1977 was chosen as the sample time interval because it was the latest full year for which all of the requisite data were available during the analysis.

E. PRINCIPAL FINDINGS

The feasibility of identifying Potentially Avoidable Maintenance actions, and categorizing them according to the manner in which they occurred, by use of an inferential technique applied to data from existing sources was successfully demonstrated.

The action quantity, cost, and NOR time impacts of the PAM

actions identified for each subject WUC, relative to the action quantity, cost, and NOR time associated with all maintenance actions on that WUC, are depicted in Figure O-2. PAM costs were estimated via multiplication of PAM action data from FY 1977 AMPAS magnetic tape data by average cost factors derived from FY 1977 VAMOSC MS data. PAM down-time values were obtained directly from the AMPAS tape data record for each PAM action. The A-7E Bombing Navigation is excluded because only a partial analysis was performed for that subsystem. The action quantity percentages in Figure O-2 were obtained by dividing the PAM action count for CNAL squadrons by the total action count for CNAL squadrons. The cost percentages were computed by dividing the fleetwide estimate of PAM cost by the total fleetwide maintenance cost from the FY 1977 VAMOSC MS. The NOR percentages were obtained by dividing the NOR time resulting from PAM for CNAL squadrons by the total NOR time for CNAL squadrons from FY 1977 hard-copy AMPAS data.

The portion of this impact which could be cost-effectively alleviated was not identified. To do this would require an investigative and economic analysis of the specific causes and solutions, and the cost associated with the implementation of these solutions.

The level of effectiveness of the inferential technique was determined as follows. The No-Repairs-Required and Reported Induced Defect categories represent actions which are explicitly reported in the MDR system. The PAM actions uncovered by the inferential logic are potentially avoidable actions not reported

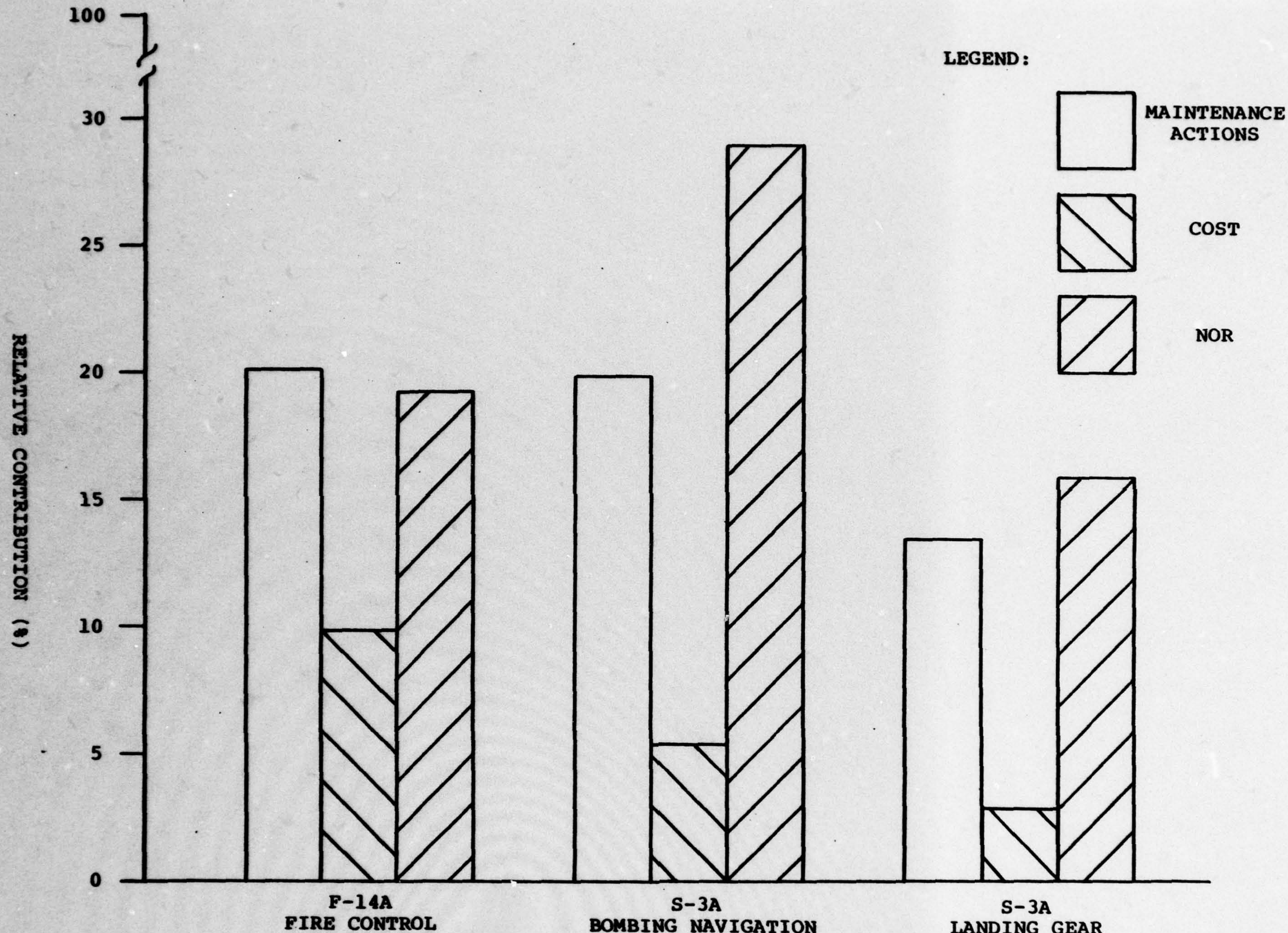


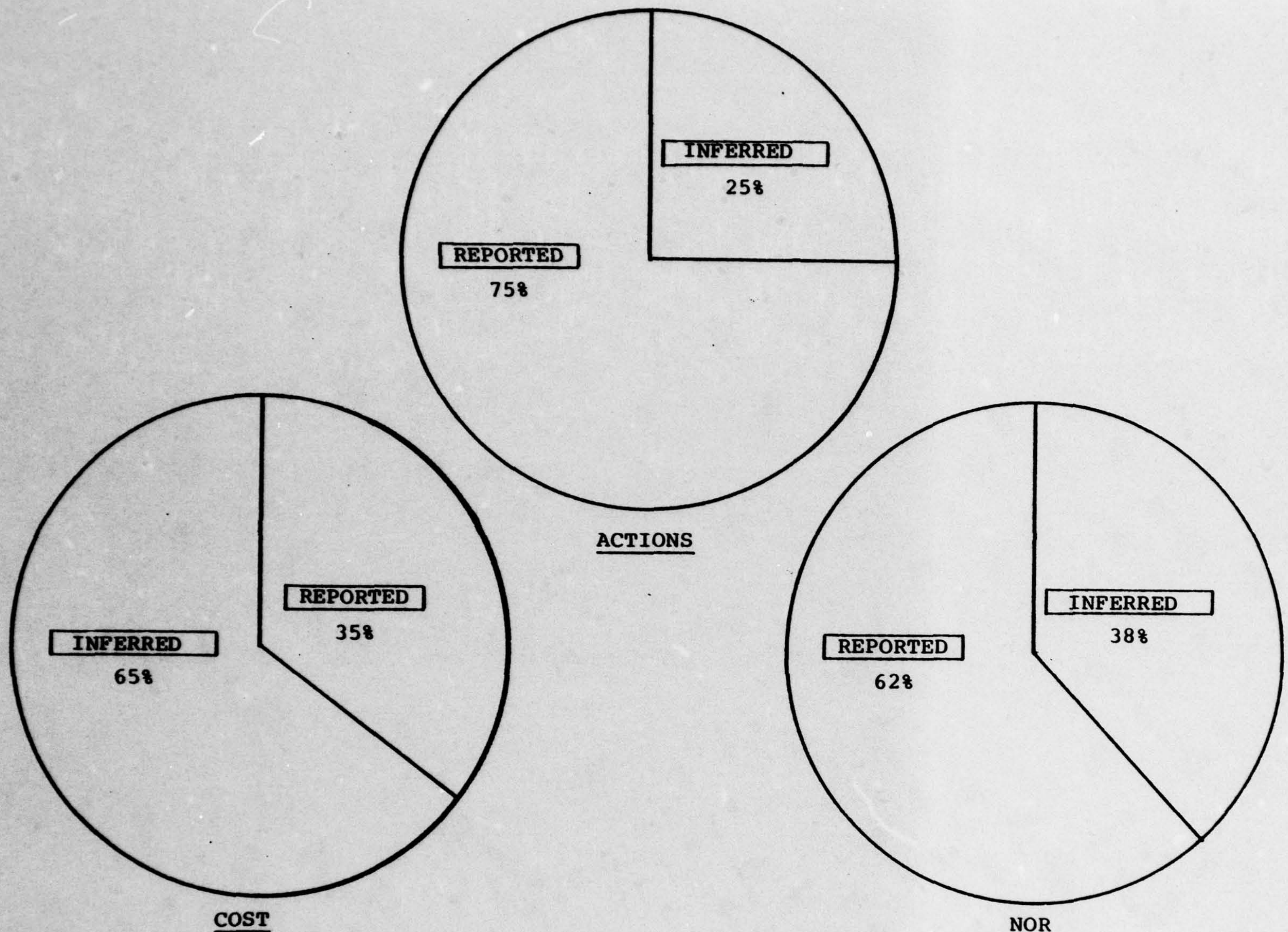
FIGURE O-2. RELATIVE CONTRIBUTION OF POTENTIALLY AVOIDABLE MAINTENANCE TO TOTAL MAINTENANCE ACTIONS, COST AND NOR TIME

as such, and are therefore denoted as inferred. The quantity of such actions, cost, and NOR time associated with reported and inferred types of Potentially Avoidable Maintenance are summarized in Figure O-3. The A-7E Bombing Navigation is excluded from this summary because only a partial execution of the inferential technique was performed.

Very few Induced Defect actions are reported as such in the MDR system and O&I-Level labor are the only cost elements incurred by No-Repairs-Required actions. Failure-To-Correct actions incur O&I-Level labor and material costs, and Induced Defect actions incur all of the cost elements presented in Table O-3. For these reasons, the average cost impact of an inferred PAM action is greater than the average cost impact of a reported PAM action.

The categories of Induced Defect and No-Repairs-Required were generally found to be the greater contributors to potentially avoidable cost and NOR time. Failure-To-Correct represented a relatively small contribution to Potentially Avoidable Maintenance and thus does not warrant as much further investigation except for specific five-digit WUCs where it is found to have a significant impact.

Potentially avoidable cannibalizations—i.e., those necessitated by false removals on another aircraft—of avionic WRAs were found to occur rather frequently, relative to the quantity of I-Level No-Repairs-Required actions. Although the S-3A is known to have experienced a supply problem during the sample time interval, the occurrence of potentially avoidable cannibalizations was



Note: Values represent F-14A Fire Control and S-3A Bombing Navigation and Landing Gear.

FIGURE 0-3. RELATIVE EXTENT OF INFERRED POTENTIALLY AVOIDABLE MAINTENANCE

found to be more significant on the subject WUCs of the F-14A and A-7E. This suggests that while the S-3A avionics suffered a high cannibalization rate, most of the cannibalizations were associated with failures, not false removals.

Potentially avoidable access actions were, in general, found to be of insignificant impact. Thus, while physical proximity of equipments results in a significant incidence of induced defects, access difficulties do not seem to significantly contribute to Potentially Avoidable Maintenance. An explanation is that suspected failures may be verified at the O Level if a remove-and-reinstall action would be required to facilitate a removal. Another explanation is that access actions may frequently go unreported.

The quantity of Failure-To-Acknowledge actions was found in all cases to account for less than 10% of the O-Level No-Repairs-Required actions. This suggests that other causes of these PAM actions are more significant. In particular, these causes may include intermittent failures, failures which can't be duplicated in a maintenance environment, false Built-In Test (BIT) indications, and unverified complaints of operations personnel.

In evaluating the numerical results of this analysis, the No-Repairs-Required Rate (NRRR) was found to be surprisingly low considering the available fleetwide data. As a result, an analysis was conducted using hard-copy AMPAS reports. The results in general, are that the squadrons of the Commander of Naval Air Force, U.S. Pacific Fleet (CNAP) exhibit a higher NRRR than the CNAL

squadrons. This disparity leads to the question, "Is the high NRRR of the CNAP squadrons accompanied by a high incidence of other types of Potentially Avoidable Maintenance?"

It was observed that the potentially avoidable depot transfer rate of the F-14A Fire Control was much lower than that of the S-3A Landing Gear and Bombing Navigation. This transfer rate was computed as the ratio of the potentially avoidable depot transfer quantity to the quantity of Induced Defect actions. The latter type of action is the only category of PAM actions subject to depot transfers. These rates are presented in Table O-4. Only depot transfers resulting from induced defects were considered. They were identified as BCM at the I Level via appropriate Action Taken Codes. The above observation may be related to the varying extent to which authorization to repair is assigned to I-Level maintenance for various weapon systems.

TABLE O-4. POTENTIALLY AVOIDABLE DEPOT TRANSFERS

T/M/S/SUBSYSTEM	DEPOT TRANSFERS	INDUCED DEFECT ACTIONS	TRANSFER RATE (%)
F-14A/FIRE CONTROL	19	290	6.6
S-3A/BOMBING NAVIGATION	90	509	17.7
S-3A/LANDING GEAR	22	126	17.5

An analysis of the computer output generated by this study was conducted at the five-digit WUC level within a selected four-digit WUC. First, as an example, the four-digit WUC with the greatest contribution to total maintenance cost was identified within the F-14A Fire Control, based on FY 1977 VAMOSC MS data, as depicted in Table O-5. It should be noted that the F-14A Fire Control is comprised of 15 four-digit WUCs.

TABLE O-5. 4-DIGIT WUC SELECTION

2-DIGIT TOTAL MAINTENANCE COST	$6,884K
HIGHEST 4-DIGIT CONTRIBUTOR	WUC 74A1
4-DIGIT TOTAL MAINTENANCE COST	$3,631K
4-DIGIT % OF 2-DIGIT MAINTENANCE COST	52.7%

Then, for each PAM category, based on PAM data for CNAL squadrons in FY 1977, the top two five-digit WUC contributors to the cost, NOR time, and NORM time associated with that category were identified within that previously selected four-digit WUC. It should be noted that WUC 74A1 is comprised of 32 five-digit WUCs. The results of this analysis are presented in Table O-6. These results demonstrate the usefulness of the technique developed for this study in pinpointing problem areas for further study and improvement.

In particular, implementation of this technique might lead

TABLE O-6. HIGHEST 5-DIGIT COST & DOWN-TIME CONTRIBUTORS (F-14A FIRE CONTROL, WUC 74A1)

		POTENTIALLY AVOIDABLE MAINTENANCE CATEGORY							
		NO REPAIRS REQUIRED		FAILURE TO CORRECT		INDUCED DEFECTS		OVERALL	
4-DIG. PAM COST	($)	69,523		8,147		45,500		123,170	
TWO HIGHEST 5-DIG. CONTRIBUTORS	(WUC)	74A10	74A15	74A1G	74A15	74A1G	74A11	74A10	74A1G
5-DIG. PAM COST	($)	21,870	10,773	2,037	789	8,500	7,846	24,645	19,264
5-DIG. % OF 4-DIG. PAM COST	(%)	31.5	15.5	25.0	9.7	18.7	17.2	20.0	15.6
4-DIG. PAM NOR TIME	(HRS)	2,777.8		76.8		93.6		2,948.2	
TWO HIGHEST 5-DIG. CONTRIBUTORS	(WUC)	74A10	74A15	74A1X	74A1G	74A15	74A11	74A10	74A15
5-DIG. PAM NOR TIME	(HRS)	1,691.8	461.6	45.0	28.6	31.0	23.8	1,715.6	492.6
5-DIG. % OF 4-DIG. PAM NOR	(%)	60.9	16.6	58.6	37.2	33.1	25.4	58.2	16.7
4-DIG. PAM NORM TIME	(HRS)	2,343.7		31.8		75.1		2,450.6	
TWO HIGHEST 5-DIG. CONTRIBUTORS	(WUC)	74A10	74A15	74A1G	74A18	74A15	74A11	74A10	74A15
5-DIG. PAM NORM TIME	(HRS)	1,512.8	409.6	28.6	2.2	31.0	15.3	1,525.6	440.6
5-DIG. % OF 4-DIG. PAM NORM	(%)	64.5	17.5	90.0	6.9	41.3	20.4	62.3	18.0

Note: Based on PAM identified by this study (CNAL squadrons only).

to the identification and mitigation of specific causes of problems on existing weapon systems, as well as the development of guidelines, policies, and/or models which could be applied in the planning and design stages of new weapon systems to the prevention of some of their Potentially Avoidable Maintenance.

It should be noted that actions attributed to four-digit WUCs were considered in this study by denoting four-digit WUCs as five-digit WUCs with "0" in the fifth position. Because many No-Repairs-Required actions are reported against the four-digit WUC at the O Level, the five-digit WUC 74A10 was found to be the biggest single contributor to overall PAM cost, NOR time, and NORM time for the four-digit WUC 74A1. No-Repairs-Required actions appear to have contributed the overwhelming portion of NOR and NORM times to the total potentially avoidable NOR and NORM times and a majority of the total potentially avoidable cost.

F. LEVEL OF CONFIDENCE IN RESULTS

The estimates of PAM action quantity, cost, and down time resulting from this study are highly conservative for the following reasons. PAM actions occurring at the depot were excluded from the study because of the exclusion of depot maintenance from the MDR system. This may be a significant category of Potentially Avoidable Maintenance.

The maximum time separation allowed to exist between pairs of maintenance actions in order to be considered potentially related was between two and three days for the various PAM

categories. These time "windows" were chosen arbitrarily, but are so small as to ensure that the actual quantity and impact of PAM actions are greater than the estimates obtained by this study. For instance, the intervention of a weekend could cause a string of related actions to be broken. This limitation might be alleviated by the use of flying hours, rather than days, for the time criteria. Such flying-hour tracking would involve interfacing with flight data records.

There are other ways in which PAM actions could escape detection by the inferential logic. If a maintenance technician incorrectly enters the part serial number on the MAF and the equipment is returned defective to supply, because I-Level maintenance either failed to correct the defect or induced it, the error is not traceable. If an item of equipment in this condition sits on the shelf for several days and does not have an elapsed-time meter or the meter time is not properly entered on the MAF, the error will escape detection because the subsequent maintenance action will be outside of the time "window." Another way in which a PAM action can escape detection is the following. A technician who induces a defect during maintenance and is aware of his error may correct it at that time with hardly a trace showing in the data system. If the induced defect occurs during what would otherwise have been a No-Repairs-Required action, the technician may code it as a corrective action. This practice would reduce the observed quantity of No-Repairs-Required actions as well.

Data validity is another area that resulted in conservative estimates. Specifically, since AMPAS data tapes provide the removal date for the O-Level action date of a remove-and-replace action, it is expected that the O-Level date would always precede the I-Level date. The reversal of this date order is one of several reasons for which records were eliminated by tape preprocessing programs. The motivation for eliminating such records was that a record with obviously erroneous data is unreliable.

It was discovered during processing that a large proportion of rejected records were eliminated because of date reversal. Two likely explanations for this phenomenon are the failure of O-Level technicians to properly fill out a MAF or the failure of keypunchers to transcribe the removal action date to the removal card—Card Type 26. If the dates are correct on the MAF, the keypunchers may be transcribing the replacement date. On the S-3A, which is notable for its supply problem during the time frame of this study, and on the F-14A, it is possible that the IMA frequently completes corrective action before the O Level can replace the equipment, thus making the data error visible.

The impact of this problem was the reduction in detection of PAM actions involving remove-and-replace or remove-and-reinstall, resulting in the elimination of an indeterminate number of sequences of related actions. The only categories unaffected are the O-Level No-Repairs-Required actions and Failure-To-Acknowledge. The category likely to be most affected is Failure-To-Diagnose since only remove-and-replace actions are involved. Indeed, few (if any) instances of Failure-To-Daignose were detected.

Down-time estimates obtained by this study are conservative for the following reason. If an aircraft is down (i.e., unable to perform any primary mission) due to scheduled maintenance for less than two hours, it is not reported NOR due to scheduled maintenance (NORMS).

Finally, the hourly labor rate applied to labor cost computations includes only the direct costs of pay and allowances. This was appropriate to an analysis intended to determine the cash-flow impact of Potentially Avoidable Maintenance. Billet cost factors, however, reflect the personnel "life cycle" costs (direct and indirect), incurred in filling a position, or billet, e.g., recruitment, training, retirement, etc. These cost elements should be considered in an economic analysis. They are more inclusive and, therefore, significantly greater in value.

In general, the limitation of an inferential technique, such as the one used for this analysis, is that there are two types of error, one of which inevitably increases with efforts to reduce the other. One type—which will be called inclusion error—occurs when a legitimate maintenance action, or group thereof, is determined to be potentially avoidable because it coincidentally satisfies the criteria of inference.

The other type—which will be called exclusion error—is the failure to identify true PAM actions because they do not quite satisfy the criteria. Weakening the criteria sufficiently would reduce the rate of exclusion error, but it would also increase the rate of inclusion error. This is because weakened criteria

allow more legitimate and potentially avoidable actions to be identified as potentially avoidable. The opposite effect occurs when the criteria are strengthened.

In designing the algorithms, selecting time criteria, and estimating input parameter values, a very conservative approach was taken so that the case for maintenance improvement would not be overstated and so that estimates obtained for potentially avoidable cost and down time would unquestionably be lower bounds.

G. ANALYSIS OF DIAGNOSTIC EFFICIENCY

The analysis of the efficiency of failure diagnosis used conventional data analytical techniques and was performed on the O Level and the I Level separately, using hard-copy AMPAS data, for the four subject subsystems of this study.

At the O Level, the Built-In Test (BIT) capability of the S-3A Bombing Navigation was evaluated by computing its sensitivity and comparing it to specified values. These specifications are not stated as rigid requirements, but rather as design goals. BIT sensitivity is composed of two parameters—False Alarm Rate (FAR) and Failure Location Rate (FLR). FAR was computed as the proportion of suspected WRA failures (including BCM actions) identified by BIT which resulted in No-Repairs-Required actions. The parameter FLR was computed as the proportion of WRA failures (including BCM actions) which were detected and located with the aid of BIT. FLR, so defined, is a combination of dependability parameters defined by the Navy's general avionics maintainability requirements.

To assess the significance of false alarms (BIT-generated No-Repairs-Required actions), the False Alarm Contribution (FAC) was computed as the ratio of false alarms to overall No-Repairs-Required actions. The estimates obtained for these parameters are provided in Table O-7.

The results appear to indicate that BIT sensitivity is very low. The specified value of FLR is 95%, compared to the estimated actual value of only 25.7%. The estimated actual value of FAR, 6.1%, while significantly higher than the specified value of 1%, is much lower (by a factor of nearly 7) than the No-Repairs-Required Rate exhibited for suspected failures not identified by BIT.

These results are predicated on the following assumptions:

- that O-Level maintenance always enters a BIT How Malfunctioned Code (HMC) when transferring to IMA a suspected faulty WRA located by BIT
- that O-Level maintenance transfers all suspected faulty WRAs located by BIT, without double checking to verify failure
- that only faulty WRAs are transferred to the depot
- and that only assemblies truly Beyond Economical Repair are discarded.

In practice, the HMC indicating the suspected cause of malfunction or code 799, indicating No Defect, may frequently be entered on the MAF. Suspected faulty WRAs located by BIT may be screened for verification, thus reducing the No-Repairs-Required action count at the I Level. It is quite possible that a

TABLE O-7. O-LEVEL DIAGNOSTIC EFFICIENCY

PARAMETERS	DESCRIPTION	BIT	NO-REPAIRS-REQUIRED RATE	
			NON-BIT-GENERATED	OVERALL
FAR	False Alarm Rate (%)	6.1	39.0	35.1
FAC	False Alarm Contribution (%)	11.5	—	—
FLR	Failure Location Rate (%)	25.7	—	—

significant proportion of the WRAs transferred to depot maintenance are determined at the depot to be non-defective.

The impact of the assumptions about maintenance and reporting practices on the results of the BIT analysis could be significant. The accuracy of the results, therefore, cannot be fully verified without conducting a field investigation.

At the I Level, the proportion of maintenance actions on Shop Replaceable Assemblies (SRAs) and sub-SRAs which are reported as No-Repairs-Required was denoted as the Failure-To-Fault-Isolate Rate (FTFIR). The proportion of all I-Level No-Repairs-Required actions attributed to SRAs and sub-SRAs was denoted as the Failure-To-Fault-Isolate Contribution (FTFIC). The estimates obtained for these parameters are provided in Table O-8.

These results indicate that I-Level fault isolation of avionics is a lesser problem for the A-7E than for the S-3A or F-14A. This may result from the greater complexity of the more modern avionics. It may also be explained as resulting from several more years of maintenance experience and maintainability improvement on the more mature aircraft. There also appears to be no I-Level fault isolation problem on the Landing Gear, probably due to easier visual fault isolation on mechanical assemblies. Corrective actions were indeed reported on SRAs and sub-SRAs, but no No-Repairs-Required actions.

The cost and down-time contribution of this form of Potentially Avoidable Maintenance would be most simply assessed by incorporating the Failure-To-Fault-Isolate category into the software developed to analyze PAM.

TABLE O-8. I-LEVEL DIAGNOSTIC EFFICIENCY

T/M/S/SUBSYSTEM	FTFIR %	FTFIC %
F-14A/FIRE CONTROL	16.6	31.8
S-3A/BOMBING NAVIGATION	11.9	38.8
S-3A/LANDING GEAR	0	0
A-7E/BOMBING NAVIGATION	2.0	10.5

FTFIR — Failure-To-Fault-Isolate Rate

FTFIC — Failure-To-Fault-Isolate Contribution

H. RECOMMENDATIONS

Based on the findings of this investigation, the following recommendations are offered.

- Since it is reasonable to suppose that all of the Services experience Potentially Avoidable Maintenance problems, each Service should investigate application of this or similar approaches to complement their on-going maintenance improvement efforts.

Data-Base System Improvements

- Field investigations should be conducted to determine the maintenance and reporting practices observed with respect to Built-In Test (BIT) at the O Level. If it is the practice of O-Level maintenance to verify BIT indications before transferring an assembly to the I Level, then the O Level is making the False Alarm Rate appear less than it actually is.

- If it is the practice of O-Level maintenance to enter the How Malfunctioned Code (HMC) indicating the suspected cause of a defect or code 799, indicating No Defect, then a revision of the Maintenance Data Reporting (MDR) forms or the procedures for completing them should be modified as necessary to allow accurate monitoring of BIT performance. In particular, maintenance technicians should be instructed to enter a BIT HMC when the suspected faulty assembly is located with the aid of BIT. An alternative

is to revise the forms as necessary to include a "Diagnostic Technique Code." This code would indicate whether BIT, Automatic Test Equipment, or conventional means were utilized in the diagnostic process.

- To facilitate the detection of Failure-To-Diagnose actions, it is recommended that the O-Level date of remove-and-replace actions be consistently coded and keypunched into the Maintenance Data Reporting system. Toward this end, the Navy should investigate the feasibility of adding a validation specification to the NALCOMIS data entry subsystem for maintenance.

- To facilitate the determination of the extent to which Potentially Avoidable Maintenance occurs at the depot, a desirable goal is to incorporate the Government Depots into the MDR system. This would provide single-thread tracking of maintenance actions through the maintenance cycle.

<u>Further Study</u>

- In the interim, the feasibility of determining, through field investigations, the extent, causes, and impact of Potentially Avoidable Maintenance occurring at the Government depots should be explored.

- Follow-up field investigations should be conducted to determine the causes of PAM problems pinpointed to

specific assemblies, as demonstrated by this study. When these causes are determined, potential solutions should be identified and their cost and effectiveness estimated. The solutions should then be implemented in those cases in which they are found to be cost-effective.

- It is recommended that further analysis be conducted to identify the degree to which each causative factor of Potentially Avoidable Maintenance would respond to investment in improvements aimed at reducing the cost/down time of PAM.

- It is recommended that a model structure be developed, incorporating the results of the previous recommendation, and that it be applied to the determination of economically sound investment decisions, for a weapon system currently in the planning stages, relative to improvement of the maintenance process.

Enhancement of Analytical Technique

- To assess the contribution of I-Level diagnosis to the PAM problem, the Failure-To-Fault-Isolate category should be incorporated into the computerized search system.

- To reduce the rate of exclusion error (failure to capture Potentially Avoidable Maintenance actions) of the search algorithms, it is recommended that the feasibility of implementing flying-hour tracking be explored.

- It is recommended that until the earlier recommendation regarding the coding and keypunching of action dates can be implemented, revisions be made to the computerized algorithms to account for the fact that a large proportion of O-Level remove-and-replace actions are assigned the wrong action date. This would be expected to result in detection of a greater quantity of Potentially Avoidable Maintenance, and could result in a significant increase in the Failure-To-Diagnose category.

Further Analysis

- Having found the relative NOR impact of Potentially Avoidable Maintenance to be greater than the relative cost impact, it is recommended that the analysis reported here be performed for the subsystems (two-digit WUCs) most critical to each weapon system's operational status. In particular, the highest NOR-contributing subsystems for each aircraft studied and its relative contribution, based on Fiscal Year 1977 hard-copy AMPAS data, is:

T/M/S	WUC	SUBSYSTEM	WUC NOR ÷ T/M/S NOR
F-14A	23	TURBOFAN ENGINE	15.6%
S-3A	14	FLIGHT CONTROLS	19.2%
A-7E	23	TURBOFAN ENGINE	23.0%

- To more accurately estimate the fleetwide impact of Potentially Avoidable Maintenance, it is recommended

that the same analysis as reported here be conducted for the squadrons of the Commander of Naval Air Force, U.S. Pacific Fleet (CNAP). Further, similar analyses should be conducted on sample Air Force and Army aircraft.

- To speed and knowledgeably focus the response to unfavorable deviations of field reliability and maintainability of newly deployed weapon systems from specified or desired values, it is recommended that the analytical system developed under this study, and enhanced as recommended above, be executed early in the operational phase of all new weapon systems. Further, the specific causes of problems pinpointed thereby should be identified and the economic model, developed as recommended above, be applied to determine a sound investment program for maintenance improvement. To measure the success of such improvement programs, the occurrence of Potentially Avoidable Maintenance should be monitored during their implementation via regular execution of the analytical system.

- To facilitate implementation of the previous recommendation, the feasibility of identifying physical and functional relationships among assemblies during the acquisition process should be explored. The assemblies considered for identification as subject to Potentially Avoidable Maintenance should be restricted to those whose counterparts on existing operational aircraft have experienced Potentially Avoidable Maintenance.